Bacterial Influence on Carbon Sequestration Below the Twilight Zone

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Abstract

The marine microbial loop is an important part of marine food webs that remineralize and recycle dissolved organic matter (DOM) which is of importance to sequester carbon in the ocean. Notably, bacteria are important for the degradation of particulate organic carbon (POC) into dissolved organic carbon (DOC), which can be stored in the ocean depths for millennia, making them vital for simulating the marine carbon cycle. This study introduces a bacterial component into the Community Earth System Model (CESM) to improve the predictions of semi labile and refractory DOC concentrations, particularly below the twilight zone with implications for understanding how changes in ocean stratification, particle flux, and the ecosystem can alter the DOC cycle. Preliminary results indicate that CESM2.1.5 with DOC cycling with the microbial loop better fit the observations. Potential shifts in the microbial loop parameterization, microbial mortality, and substrate affinity to changes in temperature and ocean circulation due to the anthropogenic carbon emission, and implications of these changes for the reorganization of marine carbon storage will be explored.

Introduction

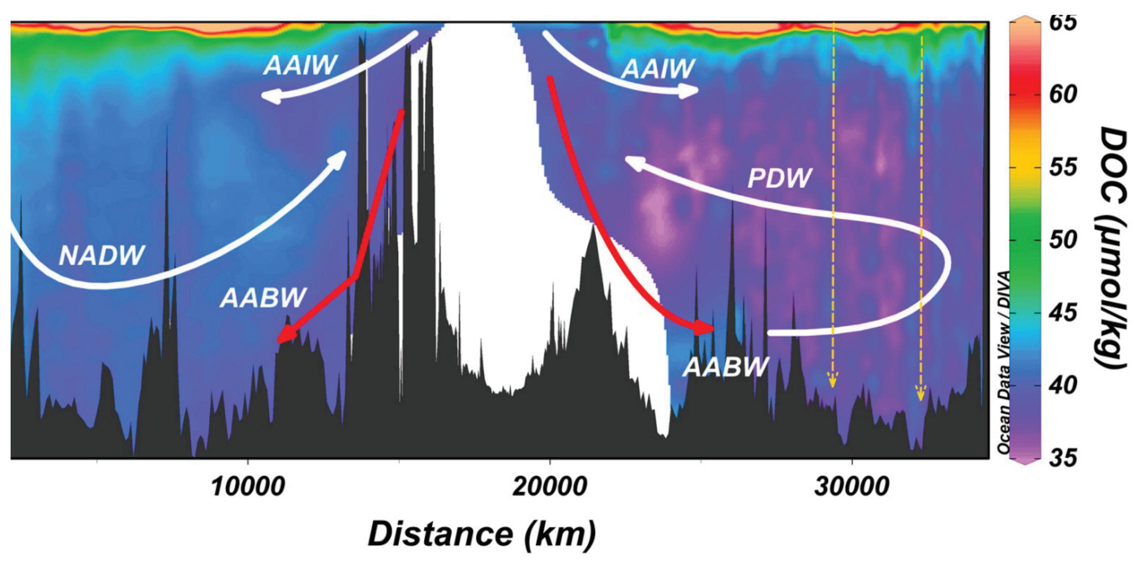


Figure 1. Vertical Distributions of DOC along A16 and P16. Solid arrows show density driven overturning patterns (NADW, AABW, AAIW, and PDW), and dashed arrows represent the apparent sinking of exported particles from the surface ocean to the deep, which serve as substrate for bacteria in the deep ocean (Hansell & Orellana, 2021).

Dissolved Organic Carbon in the Ocean:

- DOC concentrations are high at the surface in areas of primary productivity that is mixed down through the water column (Sarmiento & Gruber, 2006) and low in areas of strong upwelling (Hansell, 2001), which controls the vertical gradient seen in the ocean (Figure 1)
- DOCr has a lifetime of multiple millennia, and DOCsl has a lifetime of a few months to decades
- DOCr is difficult to simulate due to its long lifetime
- Biodegradable DOC (DOCsl) makes up 2-15% of the total DOC in the ocean

Importance of Carbon:

- Carbon is an important substrate for biological activity and is necessary for life
- The ocean is one of the largest reservoirs of anthropogenic carbon, so having a thorough understanding of how carbon is stored and moved through the various reservoirs is important for understanding how changes in climate forcings will change the ocean's storage of carbon

Objectives:

1)Develop an offline model for bacterial production that feeds on the CESM2.1.5 POC Flux

2)Test the Microbial Loop model with CESM2.1.5 POC Flux and the Martin Curve (Martin et al., 1987) to replicate bacterial concentrations, and the DOCsl and DOCr reservoirs

CESM2 Model Description

The Community Earth System Model version 2 (CESM2) consists of the Community Atmosphere Model (CAM6) and the Community Land Model (CLM5) both with the horizontal resolution of 0.9°x-1.25°, the Parallel Ocean model (POP2) with the Marine Biogeochemical Library (MARBL) and Community Ice Model (CICE5) both with the nominal resolution of 1°x1° (Danabasoglu, 2020).

DOC Cycling in MARBL

- DOC and POC are created in the surface ocean by primary production and zooplankton (Figure 2)
- A portion of DOCsl production is converted to DOCr (Figure 2)
- POC is broken down by a ballasting model (Armstrong, 2002) as it sinks from the surface, where it can be considered as substrate for bacteria below the twilight zone
- DOC is advected with the currents
- Bacteria remineralize DOCsl into dissolved inorganic carbon (DIC) and DOCr
- Other productions of phytoplankton are remineralized in the deep to ammonium, nitrate, and phosphate

Microbial Loop Governing Equations

$$B = \sqrt[n]{\frac{F\omega}{m\,(1-\epsilon_b\omega)}} \qquad (1)$$

$$M = mB^2 \qquad (2) \qquad\qquad U = \frac{1}{\omega} DOCsl\, Q_{10}^{\frac{T-T_0}{10}} B \qquad (3)$$

$$DOCr = \epsilon_r M \qquad (4) \qquad\qquad DOCsl = \frac{m}{\omega\alpha Q_{10}^{\frac{T-T_0}{10}}} B \qquad (5)$$

$$P = \omega U = \mu B \qquad (6)$$

(Equations adapted from Bendtsen et al., 2002)

B = Bacterial Biomass
M = Bacterial mortality
U = Bacterial uptake
DOCr = Refractory DOC
DOCsl = Semi-labile DOC
P = Bacterial Productivity

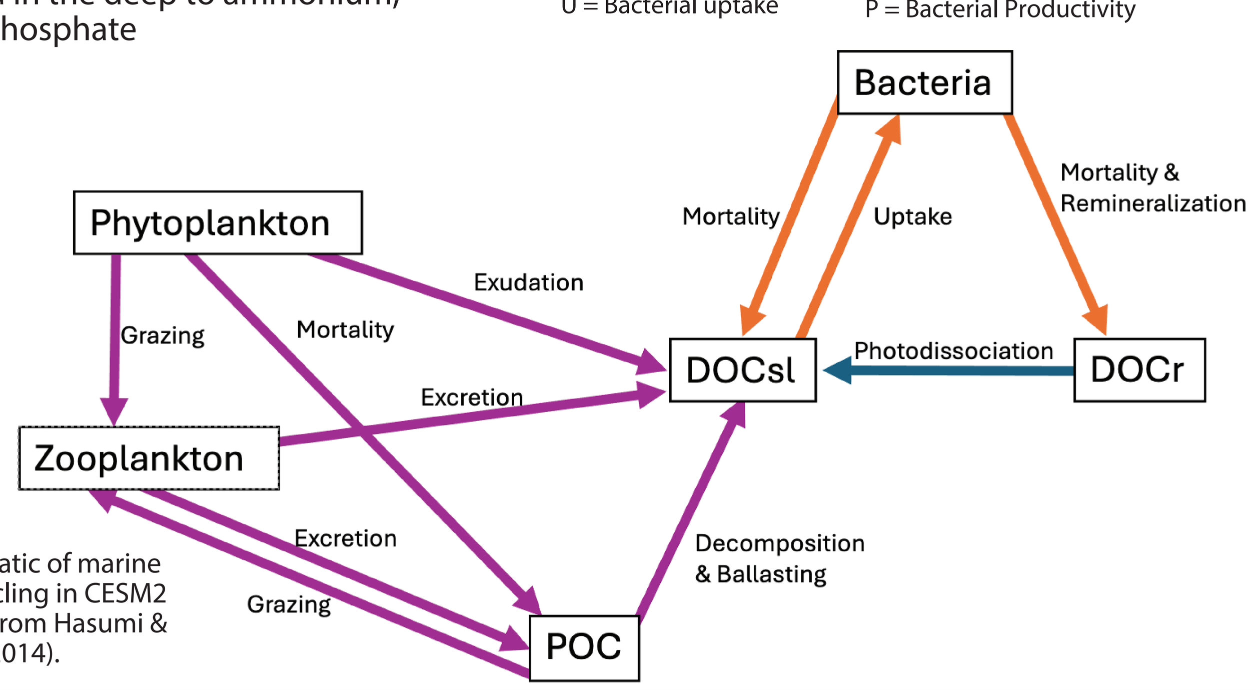
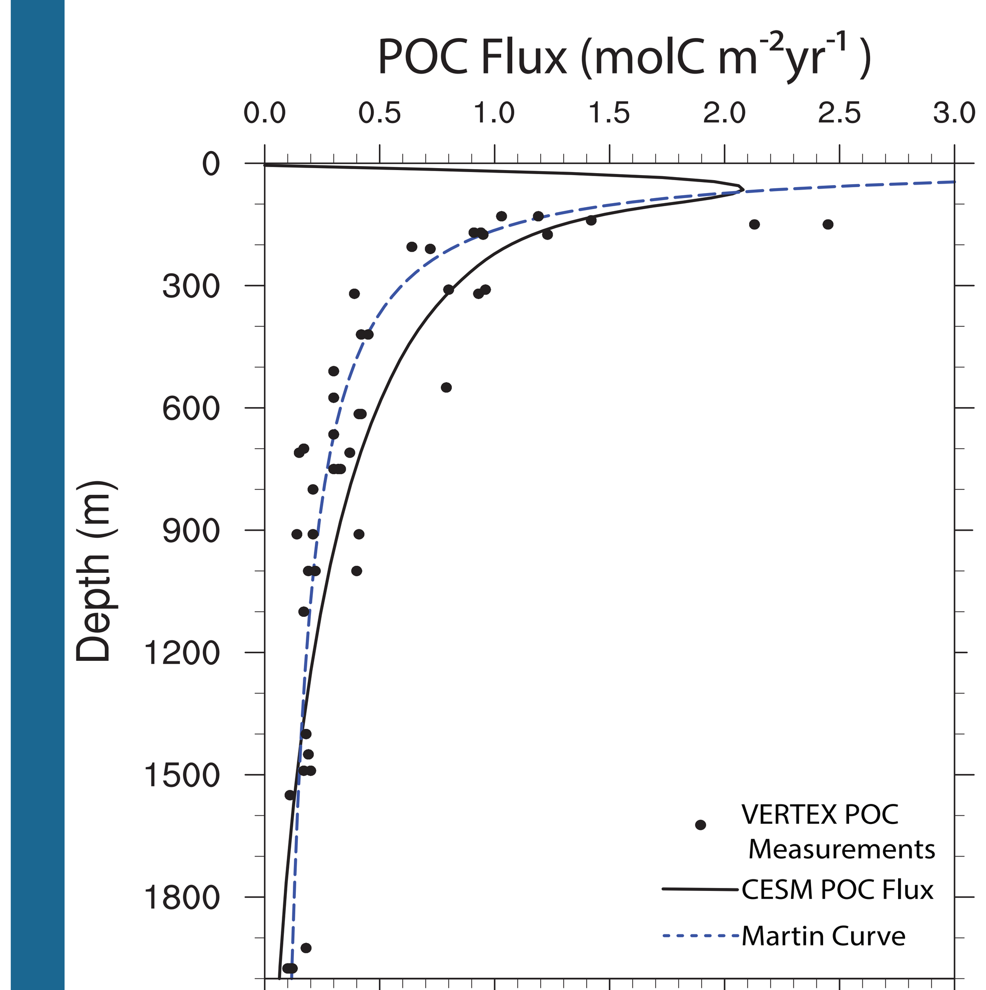


Figure 2. A schematic of marine organic matter cycling in CESM2 MARBL (Adapted from Hasumi & Nagata, 2014).

POC Flux into the Deep Sea



- The POC flux of CESM2 utilizes implicitly mineral ballasting of calcerous, silicious, and mineral material following Armstrong (2002).
- The Martin Curve is derived by a best-fit log-log transformation of observations from the Northeastern Pacific Ocean.
- 1.70 molC/m^{2}yr sinks from the surface mixed layer to be used as substrate by bacteria. This value was used as the global mean value of new production for the Microbial Loop model.

Figure 3. Vertical profiles of the VERTEX POC measurements from the norther Pacific, the log-log transformation of the normalized power function of the VERTEX observations F=F100(z/100)b (Martin et al, 1987) and the CESM2.1.5 POC flux, where F100 is the log-log intercept and b is the log-log slope.

Offline Microbial Loop Model Results

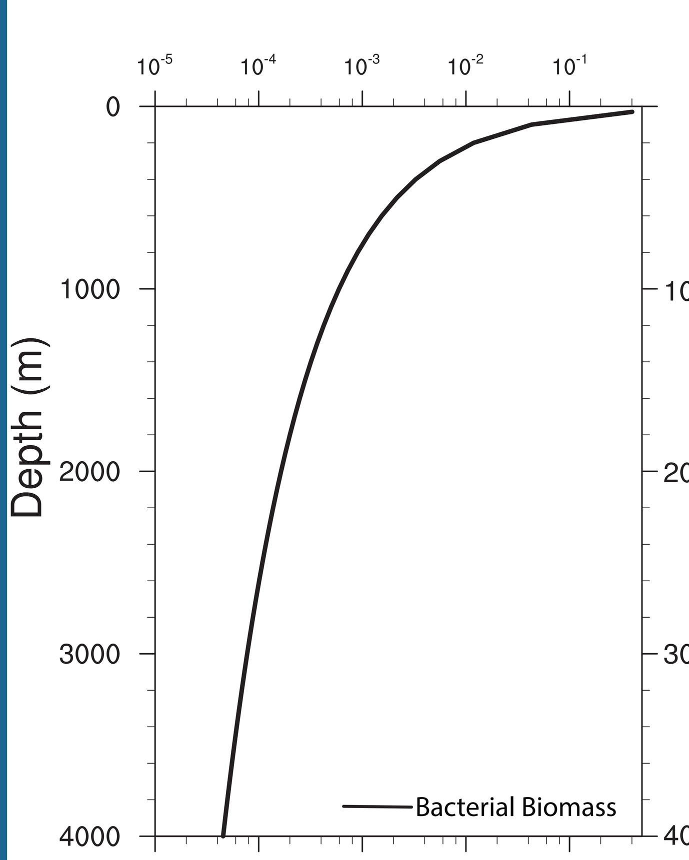


Figure 4. Calculated pool of refractory DOC from the substraction of bacterial semi-labile DOC from DOC observations based on Equations 1 and 5.

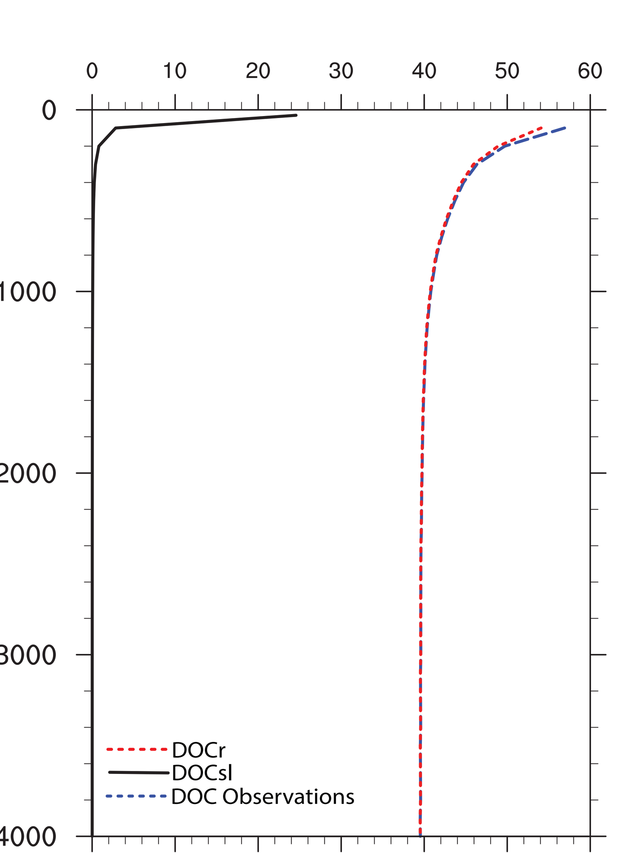


Figure 5. DOC profile with fractions of DOCr, DOCsl (Hansell & Carleson, 2015)

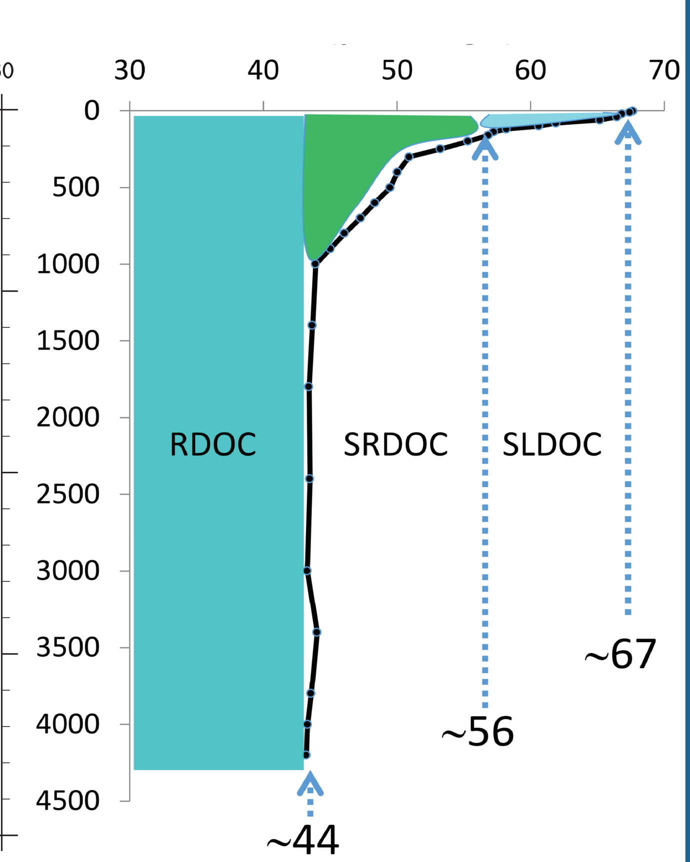
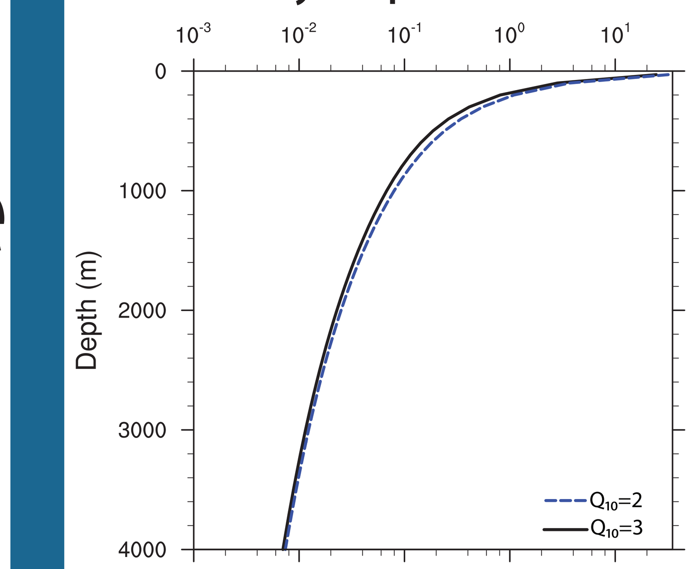


Figure 6. Simulated bacterial biomass based on the CESM2.1.5 POC flux below 100m based on Equation 1.

- Simulated Bacterial biomass is 2 orders of magnitude lower than previous studies and observations (Figure 4).
- When subtracted from observations reproduce DOCr pool throughout the water column (Figure 5).
- Bacterially produced DOCsl concentrations fit well DOCsl reservior estimates at the surface, but are too low from 200m-1,000m (Figures 5 & 6).

Sensitivity Experiments in Response to Changes in Temperature



- Q_{10}=2 is more representative of most ocean basins, compared to a Q_{10}=3 (Hasumi and Nagata, 2014) (Figure 7).
- DOCsl decreases slightly with the Q_{10}=2 value, but both concentrations decrease more rapidly than observations (Figure 7).

Figure 7. Temperature sensitivity testing of the Q_{10} temperature dependence factor of the Microbial Loop model using the value Q_{10}=2 from Hasumi and Nagata (2014) and Q_{10}=3 from Bendtsen et al. (2002) on the a) DOCsl concentration (µM C).

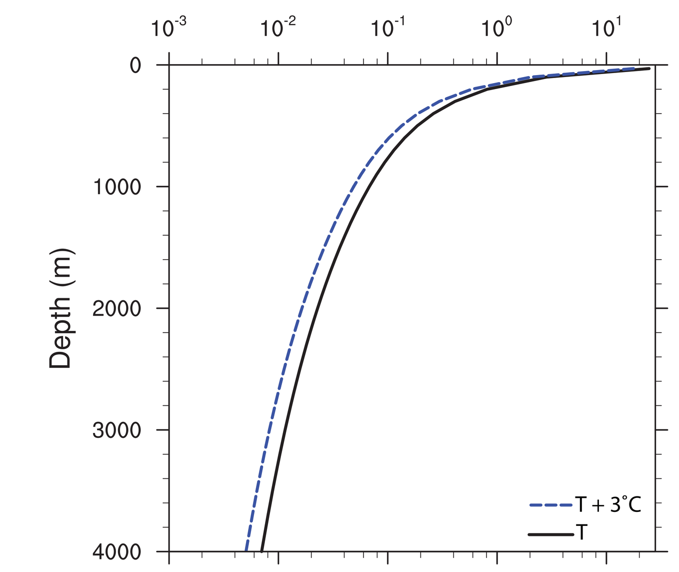


Figure 8. The effects of temperature on bacterial procuction of DOCsl concentrations (µM C).

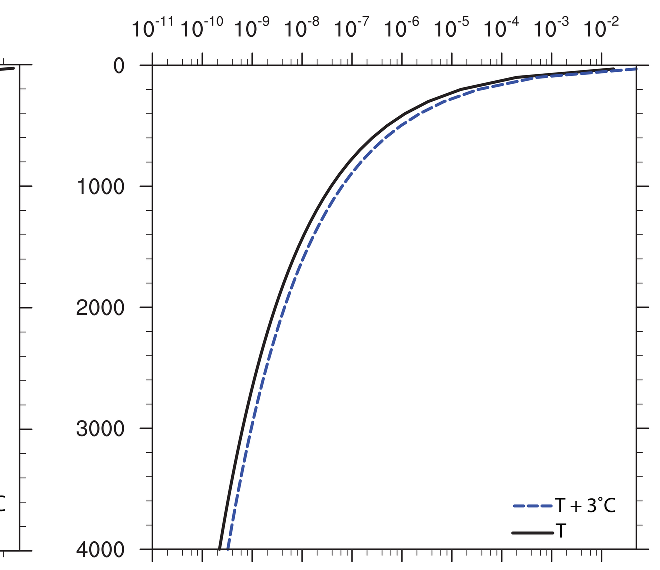


Figure 9. The effects of temperature on Bacterial Production (µM C d⁻¹).

- Increasing temperatures decrease the amount of DOCsl produced by the bacterial loop (Figure 8).
- Increasing temperatures increases bacterial production (Figure 9).

Conclusions

- Incorporating the microbial loop leads to a more detailed representaiton of ecosystem processes
- Disparities between model output and observations could be from unconstrained parameters in the microbial loop calculated from the CESM2.1.5 POC flux
- Constraining the mortality constant and temperature dependence of bacterial uptake and production is of importance for understanding how DOCr concentrations will change in a changing climate
- Changes in temperature change bacterial production, but not biomass itself

Future Work

- How sensitive is the carbon sequestration in response to changes in the DOCr pool and deep sea circulation under a changing climate?
- Which parameters of microbial loop are most sensitive to changes in ecosystem stresses and climate change?
- How does the microbial loop change the residence time of DOCr in the deep sea?

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